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SPECIFIC PROBLEMS OF DESIGNING RESEARCH REACTORS DESIGN WITH TEST LOOPS. (LOOP-TYPE REACTOR). THE MIP LOOP-TYPE REACTOR

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General

Nuclear engineering requires a thorough study of the behaviour of structural materials under intensive irradiation in nuclear power reactors. Fuel elements are the most irradiated components, the complexity of the processes occurring in such conditions calls for the need to conduct thorough tests of these elements designs in special research reactors equipped with self-contained test loops. The following thermal and hydraulic parameters, characterising the operating conditions of fuel elements and assemblies in power reactors, are simulated during such test in the first place: volume and surface heat fluxes, surface temperature, temperature, pressure and velocity of coolant. Coolant corrosive effects on fuel-assembly material should also be investigated. It is not always possible, and at times even unnecessary to simulate all the operation conditions of a fuel assembly or detailes of its design. In many cases, for instance, it is not necessary to have the real design length of fuel elements or their full number in an assembly.

It is desirable to create the required conditions for fuel assembly tests in medium power reactors, for this would reduce the cost of such tests. With thermal neutron fluxes much lower than calculated ones, the required volume and surface heat fluxes can be obtained in the tested fuel assemblies by using uranium of much higher enrichment than its calculated enrichment; moreover, it is possible to obtain the necessary surface heat fluxes by increasing the thickness of fuel element cores.

Fast reactor fuel assembly tests in a loop-type thermal reactor cannot be conducted with the real fast-neutron fluxes. This does not mean that such tests should be abandoned, as during them it is extremely easy to simulate thermal operating conditions. There are two ways of experimental investigation of the effects connected with fast-neutron fluxes: the first is a separate study of these effects by using fuel element and material samples; the second is the fast reactor fuel assembly tests in two stages - in an absorbing sheath tube, at low power density, until the required dose of fast-neutron irradiation is obtained, and subsequent tests without the sheath tube, at true heat fluxes.

Since in many cases attempts to simulate all real operating conditions for a fuel assembly bring no success, complex fuel assembly tests, close to full-scale ones, should be reasonably combined with testing separate parts of such assemblies. Some of those parts can be tested in much harder conditions than the calculated, owing to which time-limits for tests can be reduced. Several samples can be tested at a time, with hard working conditions ensured for each one of them. Complex fuel assembly tests are the final stage of this work. Naturally, during a complex test under hard conditions only that part of a fuel assembly operates effectively which experiences the greatest heat fluxes. One of the most important advantages of such tests is the fact that they are conducted under conditions created by a combined effect factors. Complex tests play an especially important role in designing fundamentally new types of fuel assemblies, while the influence of individual factors and their combinations has not yet been sufficiently studied. In such cases these complex tests make it possible quickly to determine the result of a combined effect of numerous factors.

Nuclear engineering advances in using a deeper burn-up of nuclear fuel and harder operating conditions for fuel assemblies. Fuel assemblies intended to operate in hard conditions can only be tested in sufficiently powerful loop-type reactors with high neutron fluxes. The power level of a loop-type reactor does not only depend on the maximum thermal neutron flux, but also on the volume of tests conducted simultaneously. In order to solve most of the problems connected with the development of the various branches of the atomic power industry, loop-type reactors are required with thermal neutron fluxes from 5×10^{13} to 5×10^{14} n/cm^2·sec and power levels from 5 to 100 MW.

Loop-Type Reactor Designs

Modern loop-type reactors can be classified as follows:

1. Pressure vessel-type reactors, such as the American ETR and Soviet CM-2 reactors.
2. Tank-type reactors, such as the American GETR and Belgian BR-2 reactors.
3. Channel-type reactors, such as the Soviet PФT reactor.

The core in a pressure vessel-type reactor is more homogenous, contains less structural materials and has therefore better physical characteristics than the core of a channel-type reactor. However, with thermal neutron fluxes being equal to approximately 10^{14} n/cm^2·sec, the economic effect, correspoding to the said difference in reactor physical characteristics, is not very high and not decisive in choosing the type of a loop reactor.

Potentially pool reactors are less dangerous in case of emergency. All operations with radioactive samples in such reactors are performed through a water layer, which makes such operations much simpler and greatly reduces their danger for the service personnel.

Tank-type reactors, including pool ones, have a number of substantial disadvantages:

1) access to the core is difficult, which complicates the organisation of experiments;

2) the places for test loops and their maximum diameters are fixed for the vessel design selected;

3) test loop mounting, dismounting and transportation are rather complicated, especially with regard to single-pass channels;

4) sheath tubes required for many test loops experience considerable external pressure, which leads to the introduction of additional structural materials into the core;

5) possibilities for maintenance and various improvements during the operation of the reactor are limited;

6) control system is relatively more complex in design.

In channel-type reactors, as well as in tank-type ones, there are limited possibilities for maintenance improvements during an operation; moreover, in a channel-type reactor the inter-channel space of the core is difficult to reach, which considerably reduces its experimental possibilities.

Channel-type reactors have a number of positive aspects:

1) a loop channel can be installed instead of any fuel assembly;

2) control system is much simpler in design, for there is no pressure in the space between fuel assemblies;

3) samples for irradiation in intensive fast neutron fluxes can be arranged along the axis of any fuel assembly consisting of tubular elements.

The fourth variety of loop-type reactors has been designed in the Soviet Union namely, channel-type pool reactors. They include the MP and MMP reactors. Reactors of this type have some advantages compared to other loop-type reactors.

The core, fuel assembly inlet and outlet pipes and headers of these reactors are submerged into a pool. Their core, including its inter-assembly space and reflector can be easily reached to conduct experiments.

The design of a reactor is very simple if light water is used as coolant, moderator and reflector. For physical considerations the lattice spacing should not be great in this case; this circumstance creates difficulties in arranging fuel assembly and loop channel heads and coolant feeding and removing pipes. This contradiction between the physical and design

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requirements can be eliminated by varying lattice spacing over the height.

The problem can also be solved by placing solid-moderator blocks in the inter-assembly space and the reflector. The combination of these two solutions is also possible.

Single-pass U-shaped loop channels as well as channels of the "Field tube" type can be installed in the core of such reactors.

Channel-type pool reactors are free from the abovesaind drawbacks typical of tank-type and channel-type reactors; at the same time they have all the advantages of loop channel-type reactors and pool research reactors.

One of the specific features of pool reactors is the hard requirement for water quality.

Problems of Designing Test Loop Channels

The most widespread type of installations for testing fuel assemblies consists of an in-pile loop channel and a circuit with equipment arranged in a separate box. Reliable operation of power ful test loops is secured. In special cases, other variants of such installations are used, in which the channel and the heat-exchange equipment as well as the equipment for coolant circulation are designed as a whole.

As regards coolant circulation, loop channels can be divided into two main groups:

1. Channels in which the straight and reverse coolant flow goes through the same core cell; they can be U-shaped channels or channels of the "Field tube" type in design.

2. Channels in which the coolant flows through a core cell only in one direction; they can be ordinary single-pass channels or U-shaped single-pass channels with a branch outside the core to feed and remove the coolant. If such channels are installed, with all the other conditions being equal, a much smaller amount of neutron-absorbing structural materials is introduced into the core as compared with channels of the "Field tube" type, owing to which the former channels are more preferable. For ordinary single-pass channels a specially designed bottom part of the reactor with a service room under is required. U-shaped channels with an outside branch need a specially designed reactor core, owing to which they are more often used in channel-type pool reactors. From the viewpoint of their design, channels of the "Field tube" type are universal. They can be installed in any reactor.

Structural materials for loop channels with a high-pressure and high-temperature coolant operate under very hard conditions. Apart from stresses due to internal pressure, loop channel walls experience considerable thermal stresses due to the difference between the coolant temperature in the channel and the ambient temperature, on the one hand, and internal heat mainly due to gamma-radiation, on the other. The use of thermal insulation makes it possible successfully to combat only the former source of thermal stresses. Materials for loop channels should have a small neutron-absorption cross-section; they should be sufficiently ductile, strong, heat-conducting and corrosion-resistant. For safety considerations it is very desirable that the sum of thermal and static stresses has a sufficient margin before yield point.

Unfavorable changes occur in the properties of structural materials such, for instance, as stainless steels, under the action of fast neutrons as a result the useful life of loop channels has to be reduced.

Loop channels and their circuits should withstand abrupt thermal vibrations arising during the scram shut-down and also when the reactor is quickly brought to power after a short-term shut-down.

Loop channel tests are potentially dangerous; a serious accident cannot only put a loop channel out of order, but also damage the reactor. For safety reasons, in addition to the main coolant-circulation system, there should be an emergency system. It is also important to provide continuous monitoring the tightness of both the loop channels and their outer sheath tube designed for isolation the channels from the environment. In many cases this can easily be done by checking vacuum changes in the gap between the channel and its sheath tube, with the thermal insulation of the channel being ensured simultaneously. In case of loss of tightness

the reactor is immediately shut down. Loop channels should be designed to provide for dumping coolant leakage in case of emergency.

In designing loop channels with high-temperature coolants, high temperatures should be in the core alone, which can be achieved by the use of regeneration circuits or by diluting the hot coolant at the core outlet with a cold one. The walls of pressure channels should be cooled with a cold coolant.

If the coolant is chemically incompatible with water, double insulating sheath tubes should be provided.

The МИР Loop-Type Research Reactor[x)]

This powerful multiloop reactor is now being constructed at the Research Institute of Atomic Reactors in Melekess. The vertical sections of the reactor and the pool in which it is installed, a lateral section across the core and the reactor top view with the shield plates off are shown in Figs.1, 2, 3 and 4; the orientation of the reactor vertical sections is shown in Fig.3.

The fully dismountable core and reflector block is made of hexahedral beryllium and graphite blocks. Beryllium blocks are used in the core and the inner layer of the reflector, while aluminium-canned graphite blocks are used in the outer layer of the reflector. The beryllium blocks are pierced with channels for fuel assemblies consisting of tubular elements with three lengthwise spacing ribs on the outer surface of each element (Fig.7). There are control and scram-rod holes between the blocks.

Some of the fuel assemblies are movable. Each assembly has its own drive and is, when necessary, introduced into the core from below upwards or removed, with the reactor in operation.

The 18 cells of the core are intended for single-pass U-shaped loop channels or channels of the "Field tube" type. When a loop channel is missing, it can be replaced by a fuel assembly. In order to facilitate the insertion and removal of U-shaped channels, the moderator and reflector blocks, arranged over the their horizontal sections, are secured to the very loop channels. The loop channels and pipes of loop circuits are connected in specially equipped chambers located around the reactor pool below water level.

The control and scram rod drives and those of the movable fuel assemblies are mounted on a travelling carriage. For reloading operations the rods and the movable fuel assemblies are lowered and detached from the drives, and the carriage is removed to free the space above the core.

The pressurised water, cooling the fuel assemblies, moves in the single-pass fuel assembly channels from top to bottom. Groups of channels are connected to a system of water-feed headers; the removal of water is carried out separately from each fuel channel by stationary pipes, connected within the pool by means of two headers. Under the core, there are splittype self-sealing joints connecting the channels and the water-removing pipes. This type of joint has rings made of radiation-resistant rubber and removed together with the channel. The joint had successfully stood the 100-Mrad irradiation test and proved effective for 1.000 hours of reactor operation at maximum power. The rubber rings receive a substantial portion of full-scale irradiation dose at the moment the channel is installed in the reactor. Water leakage from the reactor primary circuit into the pool through the damaged ring is made impossible by feedding clean water under a pressure exceeding the water pressure in the fuel assembly into the chamber between the two groups of rubber rings.

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x) A substantial contribution to the study of physical characteristics of the reactor was made by D.F.Davidenko and A.B.Kruglov; fundamental designing problems design were elaborated with the participation of V.V.Vinogradov, A.N.Malyshev, V.N.Maslov, S.M.Markovich, S.L.Umanskaya and V.S.Tsikunov.

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Each outlet pipe has gating valves, flowmeters, resistance thermometers and fuel-assembly leaktightness-monitoring tubes.

The beryllium and graphite blocks in the core and the reflector and also the control rods are cooled with water from the pool, circulating in an independent circuit. Water moves from top to bottom via inter-block gaps. The core vessel and the reactor equipment submerged in the pool can be dismantled when necessary.

The general view of a loop channel is shown in Fig.6. Loop channels are fully welded or have a sectional head depending on the coolant. During tests the coolant temperature at the fuel-assembly inlet and outlet and its pressure and flow rate in the channel, as well as the leaktightness of the sheath tube and the pressure tube are checked. The temperature of the fuel-assembly wall is also checked when necessary.

Reloading operations are performed by two machines: one is intended for fuel assemblies and the other for loop channels.

In the process of designing the reactor design, its most important units were tested and adjusted on special stands. Remote mounting and dismounting operations were also perfected and the necessary hydraulic characteristics obtained.

A view of the four buildings for the reactor is given in Fig.5. The reactor itself, the equipment for the test loop circuits, the pool-cooling circuits and the control panel, as well as the storage pool for radioactive articles are located in the first building. The hot cells and the critical assembly are in the second building.

Channels with spent fuel assemblies are transported to hot cells and the critical assembly under a water layer, via sluiced transport passages. The overall dimensions of two hot cells make it possible to place full-size loop channels in them. These cells, duplicating the work of each other, are designed to extract fuel assemblies by cutting or dismantling their sheath tubes. The third cell is intended for investigating reactor-tested fuel assemblies.

The continuously operated critical assembly in which spent fuel assemblies will be used will facilitate the operation of the multiloop reactor and use it more effectively as a result of the preparation in advance of reliable data relating to every new cycle of experiments.

In order to make boxes for loop circuits in immediate reach to the reactor, the primary reactor circuits is arranged in the third building, which also contains all the equipment for purifying the coolants in the reactor and loop circuits.

Special attention was paid to problems of continuously removing radioactive contaminations from the coolants.

In the fouth building are sanitary inspection rooms and administrative premises.

Radioactive samples are never raised to the room above the reactor pool; the thikness of its walls is therefore normal.

The shielding walls between the loop circuits will partly be dismountable, which will make it possible to arrange the equipment for new loop circuits in adjoining boxes if necessary. Above the loop boxes there is an annular mounting room. The equipment can be mounted and dismounted through sectional ceilings.

The main technical characteristics of the МИР reactor are given in Table 1.

The Control and Safety System

The block diagram of the system and the disposition of the fuel and loop channels, control and safety arrangements and ion chambers are shown in Figs. 1, 2, 4, 8 and 9.

The control system is intended:

a) for automatic bringing the reactor from sub-critical state to a power level equal to 1÷10% of the nominal;

b) for ensuring automatic linear increase (decrease) of power by 1÷100% of the nominal at a rate depending on conditions for heating up the loops;

c) for rapid (within 15 to 20 minutes) bringing the reactor to 50% power of the nominal after a short-term shut-down under conditions of a sharp decrease in reactivity due to xenon poisoning;

d) for short-term decreasing reactor power, introducing a movable fuel assembly into the core and increasing the reactor power to the previous level - all these operations are performed automatically;

e) for monitoring reactor reactivity under sub-critical conditions during discharge operations.

In addition, the control rods and movable fuel assemblies are used to maintain simultaneously the preset test conditions in all the loop channels.

Only compensated ion chambers are used in the control and scram systems.

The start-up and scram chambers have independent supply sources; this makes the system more reliable and ensures additional gamma-compensation in the start-up chambers.

The chambers of the automatic regulators (operating and reserve ones) have a standby power source which is automatically switched if in the main one is out of service.

When a power level equal to 1 ÷ 10% of the nominal is reached, automatic transition from period control regime to power level one is made; simultaneously the start-up chambers are automatically set in a new position in which it is possible to control power up to its nominal level. A further increase in reactor power proceeds linearly.

The linearly changed compensation currents from the power level pick-up are simultaneously applied to the three power-level amplifiers of the scram system and to the automatic regulator pre-amplifiers, compensation currents of the scram system amplifiers are always exceeding those of the regulator pre-amplifiers by 20%. This makes the reactor scram system more reliable and simplifies the work of the operator. The power changing is stopped as soon as power reached the preset level. The power may change at normaly and increased rates. In order to reduce the number of false shut-downs, the scram system is based on a "two out of three" coincidence principle.

A special programming device sets shim rods in motion when the automatic control rod reaches the position corresponding to 30 or 70 per cent of its travel, and stops them when the automatic control rod is in mid-position. The shim rods can be set in motion both separately and in groups. For the automatic regulator to be reliable under conditions and to reduce reactor start-up time, the approximately linear principle of reactivity change due to rod moving is ensured; this is achieved by making groups containing different numbers of rods, each subsequent group starting to more before the previous one stops.

Some Specific Aspects of Loop-Type Reactor Physics. МИР Reactor Physical Characteristics

To maintain the preset fuel-assembly testing conditions simultaneously in all the loops of a powerful multiloop reactor is a rather complicated problem.

In the МИР reactor, in which the maximum number of movable fuel assemblies and shim rods may, when necessary, be 22 and 20 respectively, this problem is solved as follows. In the clean reactor, all the control rods and fuel assemblies are in the lower position. As steady--state poisoning is achieved, ten additional movable fuel assemblies and six shim rods adjacent to them (see Fig.8) are moved to the upper position; by this time the prescribed testing conditions are set in all the loop channels. The power of the central loop channel is maintained at a constant level by withdrawing, as the need arises, the five shim rods around it. Constant power in the five loop channels arranged around the central one is maintained by moving the twelve main movable fuel assemblies to the upper position and inserting nine shim rods between them. The peripheral movable fuel assemblies and shim rods are moving to the lower position to maintain power in the twelve outer loop channels at a constant level. The external movable fuel assemblies, withdrawn from the core, ensure an operating reactivity margin at the end of the core life.

During the period of testing fuel assemblies in loop channels, the fuel assemblies in the reactor fuel channels are, as a rule, replaced several times. The reason for this is the difference in burn-up rates due to thermal neutron depression flux in the loop channels. Such

operating conditions make it possible to take measures helping to maintain the preset fuel-assembly testing conditions in the loop channels: rearrangement of channels containing fuel assemblies with different burn-up depth; insertion into some of the channels of fuel assemblies with a reduced number of fuel rings or fuel assemblies with central absorbers; replacement of some the fuel channels in one of the operating cycles by beryllium followers; changing the effectiveness of some rods and absorbers in channels with movable fuel assemblies.

In view of the need to maintain constant power in the loop channels, the power of the reactor during its operating cycle is gradually changed because of the difference in burn-up rates in the loop and fuel channels. The best economic characteristics and the longer operating cycles of a loop-type reactor can be obtained by using the additional fuel charge principle during operation. In this case the average power of the reactor per operating cycle is lower than its maximum value.

However with a great number of loop channels operating simultaneously the need to maintain their power constant results in the fact that the economic effect of additional fuel charging in the process of operation is not complete. In this case it chiefly depends on the reduction of that part of the core operating charge which ensures an operational excess reactivity margin.

After shut-down of the reactor, operated at great specific fuel power, there occurs a rapid negative change in reactivity due to xenon-135 poisoning. The rate of xenon build-up immediately after shut-down is directly proportional to the power of the reactor before shut-down and practically does not differ from the rate of xenon-135 build-up in the operating reactor, since they both depend on the rate of iodine-135 disintegration.

In the MMP reactor, after 30 min shut-down, poisoning increases about two-fold as compared with steadystate condition. Towards the end of this interval the reactor should be brought to a power level equal to approximately 50 per cent of nominal, so as to discontinue further loss of reactivity beyond the limits of the $\sim$ 4 per cent operational excess reactivity margin provided for in the project.

The maximum poisoning rate is $\sim$ 1/250 β_{eff} per second. In order to bring the reactor to power within 10 to 15 minutes after a 15÷20 min shut-down, the project provides for a sufficient rate of positive change in reactivity, when the control rods and movable fuel assemblies are shifted in a sub-critical reactor, up to 1/20 β_{eff} per second, which corresponds to the nuclear safety standards now in force in the Soviet Union.

Short-term shut-downs can take place in case of false scram signals. There may also be planned short-term shutdowns, say, for repair purposes or for the withdrawl of irradiated samples and the insertion of new ones. If the time-period for one shut-down is insufficient for such operations, reated shut-downs can be used for the purpose. Fig.10 shows a reactor-poisoning curve in conditions of regular shut-downs and start-ups.

In some cases, when the reactor has to be shut down for several hours for repair purposes, it can be operated prior to such a long-term shut-down in special conditions[x)] shown in Fig.11. If repair work is carried out, say, during five hours, then as can be seen from the curves in Fig.11, the reactor can be brought to power 8 hours earlier than in case of a regular shut-down.

One of the specific features of a multiloop reactor lies in the fact that its core and reflector have heterogeneous physical properties. Considerable thermal neutron flux depressions are, as a rule, observed where the loop channels are arranged; their magnitude is substantially affected by the physical properties of the materials surrounding the loop channels. This depression decreases if the materials are good moderators and the thermal diffusion length in them is great. It also decreases if gas gaps around the loop channels are created;

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x) See В.Н.Артемкин "Атомная энергия" /1964 г., in print/.

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this should, of course, be done with due regard for nuclear safety requirements. It is desirable that loop channels which do not greatly disturb the neutron fields should be installed in the neutron traps and also surrounded with gas gaps or materials with good physical properties.

Loops with a hydrogen-containing coolant should be arranged in the core, using the thermal-neutron generation effect inside the channel. When a loop channel is installed in the reflector, there occurs great power density angular heterogeneity in the fuel assembly under test. This heterogeneity can be eliminated by using neutron absorbers or by creating a variable gas gap between the loop channel and its sheath tube of much larger diameter at the expense of their eccentric disposition.

Tables II and III give the physical characteristics of the MHP reactor.

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Table 1

The Main Technical Characteristics of the MMP Reactor

1. Maximum power:	
of the reactor	100,000 kw
of a fuel assembly	4,000 kw
2. Coolant flow rates:	
primary circuit	2,000 t/hr
pool circuit	1,000 t/hr
maximum power-density fuel assembly	80 t/hr
3. Pressure in the maximum power-density fuel assembly:	
at the core inlet	12.4 kg/cm^2
at the core outlet	8.6 kg/cm^2
4. Coolant temperatures:	
at the channel inlet	40°C
at the channel outlet	83°C
at the moderator blocks inlet	40°C
at the moderator blacks outlet (average)	50°C
5. Data on the fuel assemblies and their operating conditions at a power of 4,000 kw:	
length of the active part	1,000 mm
heat transfer surface	1.7m^2
uranium-235 content	350 g
maximum heat flux	3.4 x 10^6 kcal/m^{2}hr.
coolant velocity	10 m/sec
maximum fuel element can temperature	147°C
subcooling	25°C
6. Some geometrical dimensions:	
lattice spacing	150 mm
fuel assembly sheath tube dimensions	78 mm o.d/7 mm i.d.
maximum loop channel diameter	150 mm
control and safety rod diameter	23 mm
moderator block height	1,100 mm
inter-block gaps	1.5 mm
7. Materials:	
fuel	90 per cent enriched uranium
fuel composition	uranium-aluminium alloy
fuel element cans	alluminium alloy
fuel assembly, control and safety rod sheath tubes	zirconium
control and safety rods	stainless-steel-canned boral
absorbers over the movable fuel assemblies	stainless-steel-canned cadmium
core vessel with the support grid	aluminium alloy
headers, fittings, cooling circuit pipes pool facing, parts of the control-and-safety-system carriage	stainless steel

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8. Core and side-reflector composition by volume:

core .... beryllium 0.71
water 0.176
aluminium 0.0948
zirconium 0.0185
uranium 0.00107

the first reflector layer ...beryllium 0.96
water 0.04

the second reflector layer ..graphite 0.853
water 0.0199
aluminium 0.0521
gas gaps 0.0755

Table II

	Element Nuclear density				n x 10^{-20} nuclei/cm^3			
	U^{235}	U^{238}	Be	Zr	Al	H	O	C
Core	0.46	0.0512	863	7.82	57.1	118	59	-
Ist layer of side reflector	-	-	1180	-	-	27	13.5	-
2nd layer of side reflector	-	-	-	-	-	31.4	6.65	705

Table III

Physical Characteristics of the MMP Reactor

Thermal utilization factor 0.8
Resonance-escape probability 0.985
Infinite multiplication factor .... 1.63 x)
Diffusion area, cm^2:

core 17
1st layer of side reflector 243
2nd layer of side reflector 678

x) Without taking into account $(n, 2n)$, (γ, n) and (n, α) beryllium reactions.

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Neutron age, cm^2:	
core	63
1st layer of side reflector	75
2nd layer of side reflector	335
Reflector savings, cm:	
side reflector	20.3
top or bottom reflector	9
Total reactivity of the core with 61 fuel assemblies, %	30 x)
Reactivity balance, %	
steady-state poisoning	4
burn-up	14
loop tests	12
operational reactivity margin	4
Effectiveness of the control and safety rods, %:	
safety rods (6 units)	3.7
shim rods (20 units)	8.0
movable fuel assemblies with absorbers (22 units)	15
Maximum specific power:	
volume, kw/1	280
fuel, kw per 1 kg of uranium-235	20.000
Thermal neutron flux in the uranium (at neutron gas temperature of 293°K), n/cm^2sec.:	
maximum	5×10^{14}
average	$2,5 \times 10^{14}$
Maximum fast neutron ($E \geqslant 0.5$ Mev)	3×10^{14}
Maximum thermal neutron flux in the central trap	1.5×10^{15}
Burn-up of uranium-235 in fuel assemblies, %:	
maximum	40
average	30
Core life at a power of 100 MW, days	21
Fuel loading change during core life, kg of uranium-235	11-8
Maximum number of fuel assemblies in the core	33

x) Reactivity balance was calculated according to the formula: $1 - \rho = \prod^{i} (1 - \rho_i)$.

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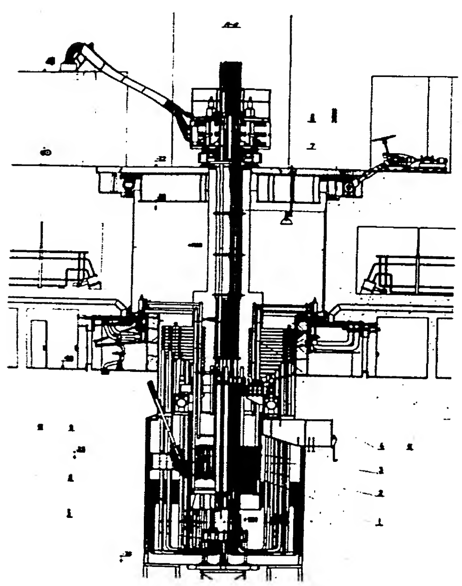

Fig.1. Cross section of the reactor
1. Core and reflector pile blocks; 2. Fuel assembly; 3. Movable fuel assembly; 4. Coolant feeding headers; 5. Lower sealing unit; 6. Fuel assembly coolant outlet pipes; 7. Rotating upper shield plates; 8. Place for control-and-safety- rod and movable fuel assembly drive; 9. Movable ion chamber; 10. Box with equipment for connecting loop channels to loop circuits. 11. Loop channel

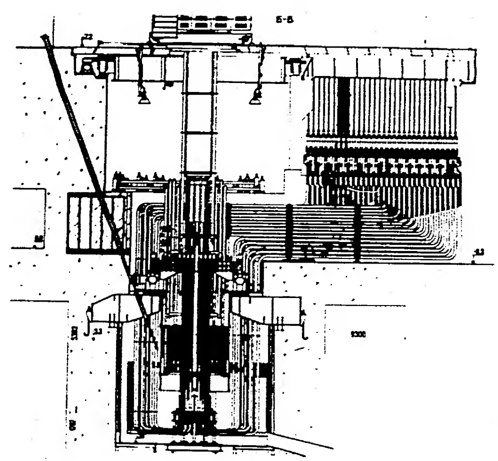

Fig.2. Longitudinal section of the reactor

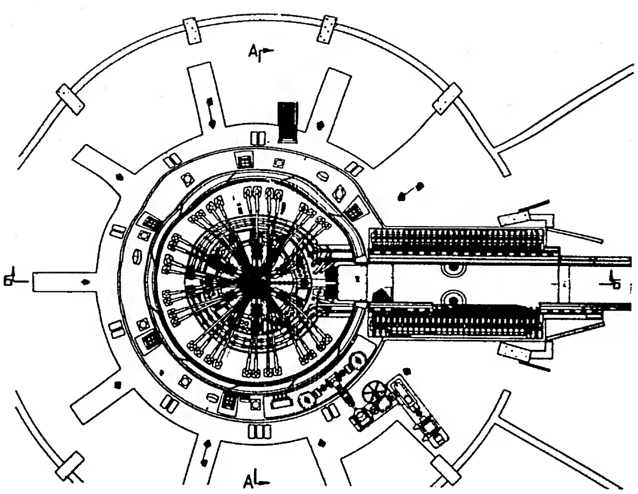

Fig.3. Top view with shield plate removed

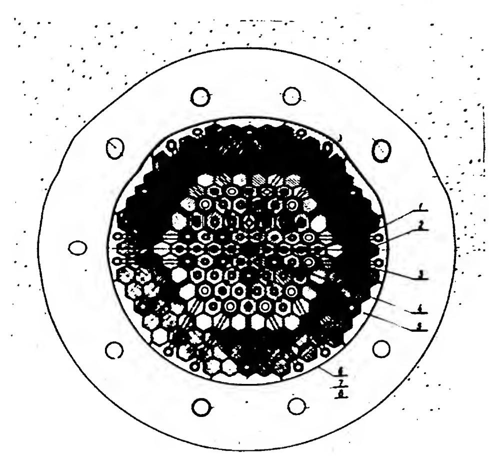

Fig.4. Core horizontal section
1. Beryllium block; 2. Aluminium-canned graphite block; 3. Fuel assembly; 4. Loop channel; 5. Aluminium follower; 6. Core vessel; 7. Movable ion chamber channel; 8. Fixed ion chamber channel

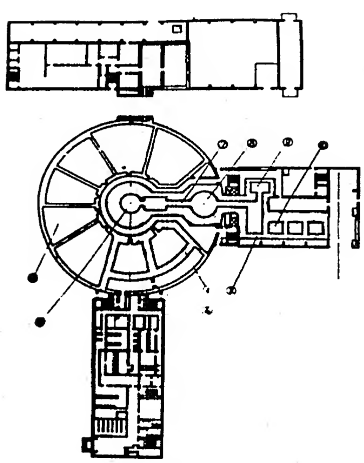

Fig.5. Horizontal section of the reactor buildings
1. Building for the reactor, test loops and storage pool; 2. Building for hot cells and critical assemblies; 3. Building for coolant purifiction, reactor primary and secondary cooling circuit equipment and auxiliary systems; 4. Building with sanitary inspection rooms, administrative and laboratory premises; 5. Reactor pool; 6. Test loop box; 7. Transportation passage; 8. Storage pool; 9. Critical assembly pool; 10. Hot cell

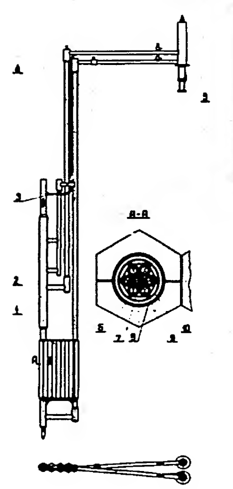

Fig.6. General view of a single pass (U-shaped)loop channel
1. Beryllium pile blocks belonging to the loop channel;2.Main tube with sealed head; 3.Thermocouple tube; 4.Inlet and outlet coolant pipes; 5.Loop circuit junction; 6. Fuel element; 7.Collant; 8. Pressure tube; 9. Sheat tube; 10. Vacuum gap

Fig.7. Fuel assembly

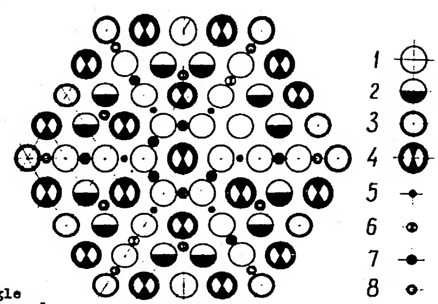

Fig.8. Channel and controls arrangement diagram
1. Fuel assembly; 2. Movable fuel assembly; 3. Additional movable fuel assembly; 4.Loop channel; 5. Safety rod; 6. Automatic control rod; 7. Shim rod; 8. Additional shim rod

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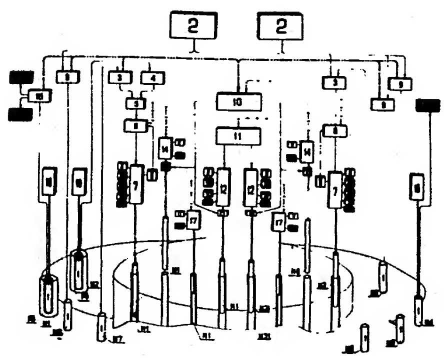

Fig.9. Block diagram of the control and safety system

1. Ion chamber; 2. Power demand and its linear rate of change controller; 3. Preamplifier; 4. Automatic start-up amplifier; 5.Automatic operating conditions switch (period regulation-level regulation); 6. Magnetic amplifier; 7. Automatic control rod servodrive; 8.Tacho-generator; 9. Safety system amplifier; 10. Safety system diagram; 11. Programming device; 12. Shim rod servodrive; 13- Electromagnetic clutch; 14. Safety rod servodrive; 15; Safety system period amplifier; 16. Highly sensitive ion chamber servodrive; 17. Movable fuel assembly servodrive;

——·... ———— scram signal

—— x ———— signal from the operator panel

———————— mechanical coupling

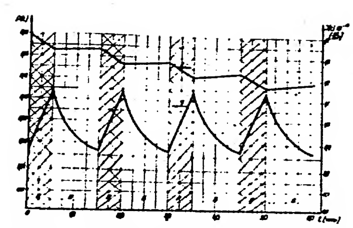

Fig. 10. Reactor poisoning periodical shut-downs and start-ups

A. Shut-down; B. Operation at full power; 1. Poisoning curve; 2.Iodine concentration change

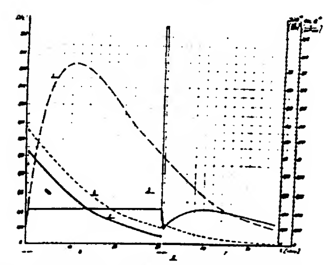

Fig.11. Special operating conditions of the reactor before a long-term shut-down

1. Ordinary positioning curve after shut-down; 2. Average thermal neutron flux; 3. Poisoning curve in conditions under consideration; 4. Iodine concentration change; A. Short-term shut-down; B.Neutron flux change as curve 2; C.Operation at full power; D. Long-term shut-down